

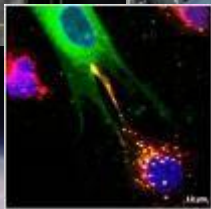
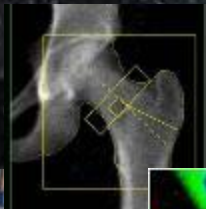
# Integrating Bioregenerative Foods into the Spaceflight Food system

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# Bioregenerative Foods

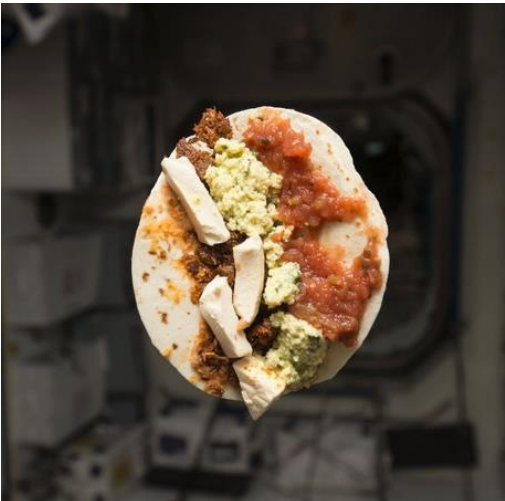
- Why do we want to introduce bioregenerative foods?
- What are the limitations to introducing them?
- How do we introduce them?





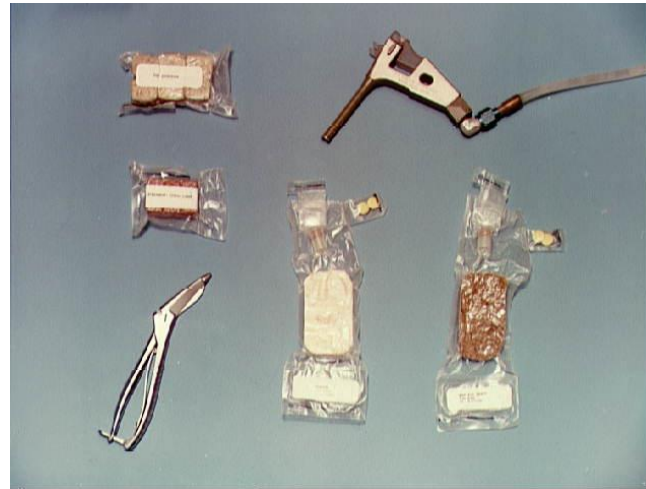


# Space Food System Challenges



- Multi-year shelf stability
- No cold storage
- No cooking
- Limit crumbs and free liquid
- Minimal food transfer
- No washing or reuse of containers
- Minimal crew time for food preparation
- Resource Restricted – e.g. 2.5 L water per person per day

# Food Systems: Mercury to Apollo



MERCURY

GEMINI

APOLLO





# Food Systems: Skylab to early International Space Station



SKYLAB



SHUTTLE



INTERNATIONAL SPACE  
STATION



# International Space Station 2008-Current



## 200 options in 8 Standard Menu Categories

1. Breakfast
2. Rehydratable Meats
3. Meat and Fish
4. Side Dishes
5. Vegetables and Soups
6. Fruits and Nuts
7. Desserts and Snacks
8. Beverages



### **Bulk Overwrap Bag (BOB)**

A set of 8 BOBS (one per menu category) will feed a crew of 3 for 7-9 days

Limited crew specific food, fresh food, condiments

No food refrigeration available on ISS

Shelf life of 1-3 years under room temperature storage



# The case for prepackaged food

Goal: Exploration Food System that Promotes Crew Health And Performance

**Food Safety Confirmed Prior to Launch**

**Less Infrastructure**

**Less Crew Time**

**No Risk of Food Scarcity**

**Demonstrated ability to support  
human health and performance for 6-  
12 months**





# ISS Compared to Mars



## International Space Station:

- 6 month microgravity missions
- Radiation impact understood
- Regularly scheduled resupply
- No refrigerators or freezers for food storage, all food processed and prepackaged
- 7-9 day standard menu cycle augmented by crew preference foods



## Mars Expedition Scenario:

- 2.5 year mission; micro- and reduced gravity
- Radiation impact is unknown
- No resupply; food may be prepositioned
- Availability of refrigerators or freezers for food storage is undecided
- Current food system is mass constraining and will not maintain nutrition/acceptability



# The Constraints of Prepackaged Foods

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**Nutrient Degradation**



**Quality Limitations and Degradation**



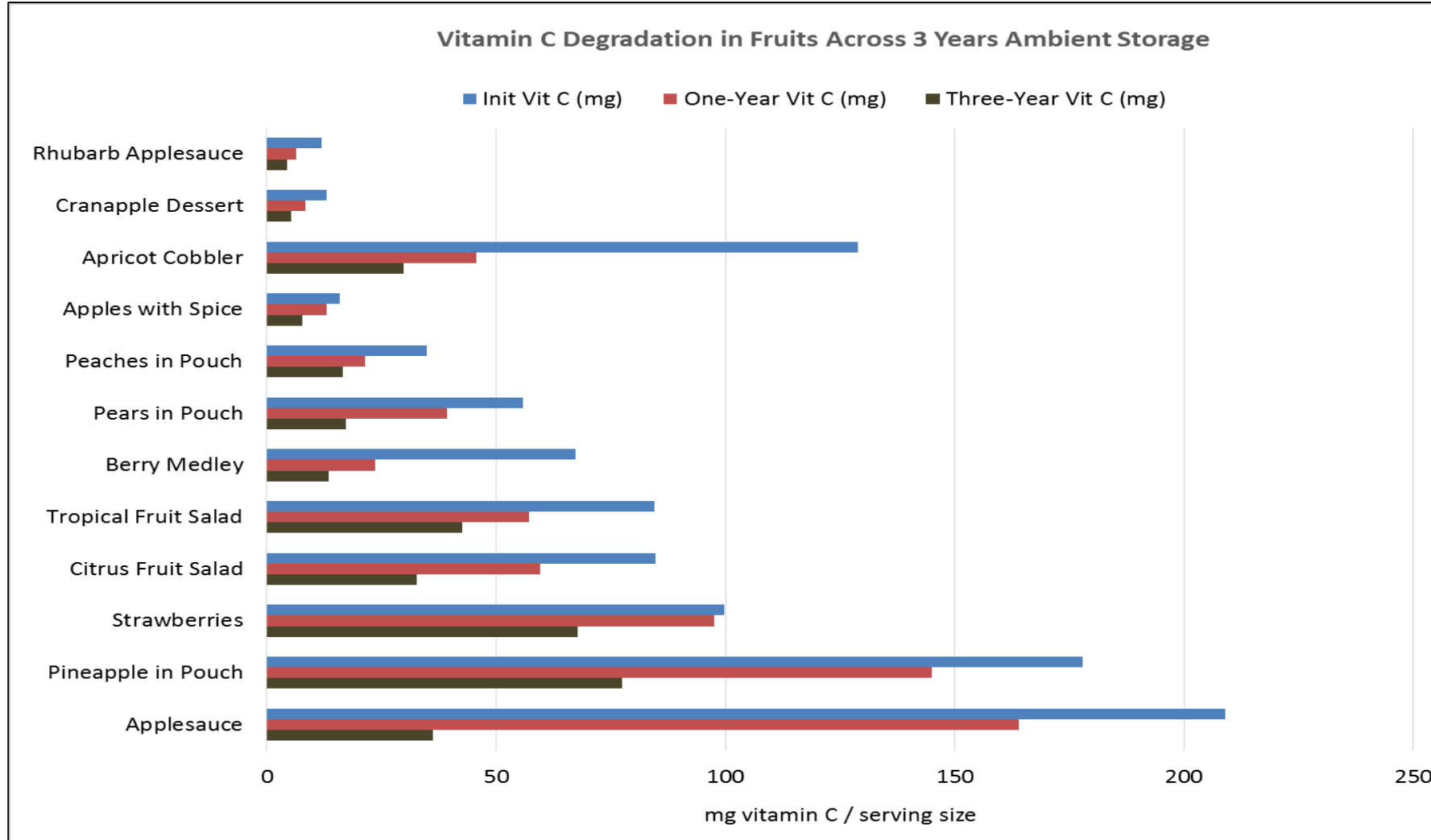
**High Mass and Volume**

**No customization**





# Exploration Food System Challenge: Micronutrient Degradation



Cooper et al. npj Microgravity. 2017.





# Functional Foods and Bioactive Compounds

Functional Foods provide  
health benefits beyond basic nutrition  
when consumed at effective levels as part of a  
varied diet

(Hasler 2002)

Include compounds such as:

- Flavonoids
- Lycopene
- Lutein
- Sterols
- Omega-3 fatty acids

Potential health benefits:

- Improved nutritional status/bone health
- Reduced inflammation and oxidative damage
- Improved immunity
- Improved microbiota diversity
- Microbial production of beneficial metabolites

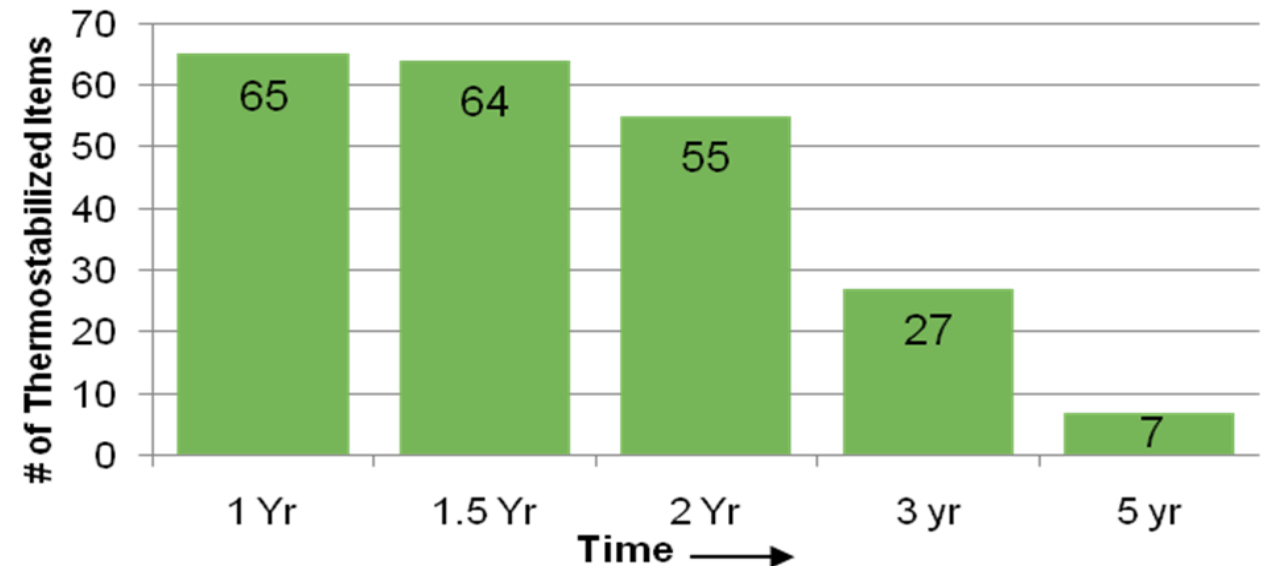




# Exploration Food System Challenge: Acceptability and Variety



- Food quality relates to health and performance
- Food variety is limited in a closed system
- Food becomes more psychologically important with increasing mission duration



(Catauro. Journal of Food Science. 2011)





# Prepackaged Food Strategies: 5 Year Shelf Life



Focus on nutritional stability, acceptability, health promotion

## Formulation



Fortification

Ingredients and  
Matrix

Functional Foods

Variety

## Processing



Microwave  
Assisted Thermal  
Sterilization  
(MATS)

Lyophilization  
Improvement

Reduced  
Moisture

## Packaging



Improve barrier

Reduce Mass

Improve Method

Improve Processing  
Compatibility

## Environment



21°C

-80°C

Temperature

Atmosphere

Radiation

Microgravity

Partial Gravity



# The Case for Bioregenerative Foods

**Agri-Therapy**

**Psychological Appeal**

**Higher Nutrient Density**

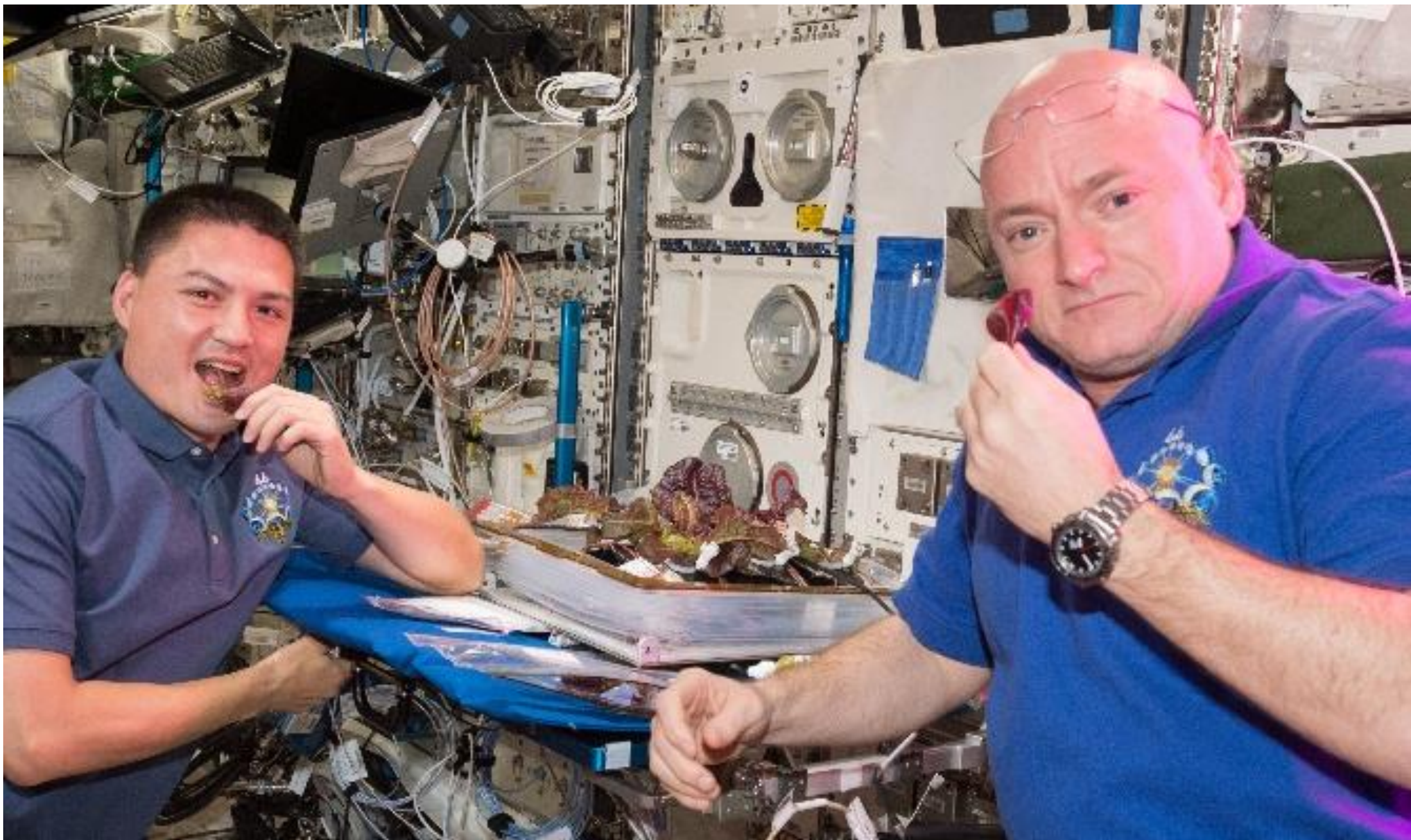
**Fresher Food / Quality**

**Variety / Customization**

**Goal: Earth Independence**















# The constraints of Bioregenerative Foods



**Risk of Food Scarcity**

**Microbiological Risk**

**High Crew Time Requirement**

**Infrastructure**

**Low Technology Readiness Level**







# Bioregenerative Food Strategies: Integrate Salad Crops

- First missions only pick and eat; supplement prepackaged food
- Validate technology and reliability of crop growth procedures
- Increase dependence on crops with technology maturation





# Bioregenerative Key Food Points



- Establish Safety
- Establish Nutrition and Acceptability
- Ensure Variety
- Mature all related technologies
- **Promote Human Health and Performance**

